

"THE ELECTRON PRESSURE IN THE ATMOSPHERES OF LATE-TYPE DWARFS"

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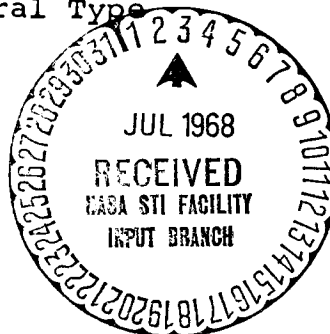
Some years ago Vardya and Böhm ⁽¹⁾ examined the profile of the CaI resonance line at $\lambda 4227\text{\AA}$, in the spectrum of the M dwarf HD 95735, and came to the conclusion that if the effective temperature of the star is lower than 3400°K , unknown sources of opacity may be present in its atmosphere.

This arises because the pressure-broadened profile predicted by the lower-temperature models is far broader than the profile actually observed. The introduction of an additional opacity changes the relation between gas pressure and optical depth, so that on the whole the line is formed in regions of lower pressure and therefore is not so broad.

In the course of observations which I made some years ago at the Observatoire de Haute-Provence, in France, at the coude spectrograph of the 193 cm telescope, I studied the profile of $\lambda 4227$ line in several late-type dwarfs, ranging in spectral type from K7 to M3. The stars observed were:

TABLE I

Star	Spectral Type	Dispersion used ($\text{\AA}/\text{mm}$)
61Cyg B	K7 V	10
HD 88230	GPO PRICE \$ <u> </u> AM 0	10, 20
HD 95735	CFSTI PRICE(S) \$ <u> </u> AM 2	40
BD+36 ⁰ 2393	Hard copy (HC) <u>3.00</u> AM 2	40
HD 119850	Microfiche (MF) <u>.65</u> AM 3	40



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The remarkable feature, as seen in Figure 1, is that the profile hardly varies among these stars; moreover the agreement with the published profile of Vardya and Böhm is quite good.

On the other hand, the profiles predicted by model atmospheres were far broader than those actually observed, so that the discrepancy suggested by Vardya and Böhm exists here too. The models used have been described by me elsewhere⁽²⁾. Here I shall only remark that changing from a model in radiative equilibrium, to one which goes over to an adiabatic at low optical depth, has practically no effect on the predicted emergent profile. The figures 2 and 3 illustrate the sense of the discrepancy, which of course becomes more serious as one goes to lower-effective-temperature models. A similar discrepancy exists for the region of the CaII H and K lines (figure 4), but here the continuum level cannot be defined at all, so not much weight can be attached to this.

Now this disaccord also manifests itself in the same sense for the Na D lines (figure 5); therefore, if it is to be explained by an unknown absorber, it will mean that there is little wavelength dependence involved. In the atmosphere of a cool star, one way of obtaining such a nearly gray supplementary absorption, would be to have an excess electron pressure and thus a higher concentration of H^- , the negative hydrogen ion.

It may seem that departures from local thermodynamic equilibrium (LTE) are unlikely in the dense atmospheres of late-type dwarfs. However, it should be noted that the electron densities are quite low ($N_e \sim 10^{12} - 10^{13}$); thus, provided that collisions involving neutral particles, such as H atoms or H₂ molecules, are relatively ineffective in ionization or recombination, a strong radiation field could quite easily dominate the ionization equilibrium and lead to departures from the Saha equation.

The question then is: which metals are suitable candidates for over-ionization? Also, is the necessary radiation field available? In order for over-ionization to have an effect, the metal must not be already nearly totally ionized according to LTE. In the case of the stars observed, near spectral type Mo, this excludes such metals as potassium, sodium, and calcium, since an overionization will only affect the neutral population without changing the electron pressure. Examination of the LTE equation of state for these atmospheres (see, eg. Vardya⁽³⁾) shows that magnesium and silicon could furnish many electrons if there were departures from LTE. However, for these metals we cannot seriously expect such departures, since the bound-free absorption of the neutrals will practically cut off all the radiation in the relevant wavelengths (1400-1700 Å) (see, e.g. Gingerich⁽⁴⁾). Thus it seems that the suggested mechanism must be inoperative in these stars.

It may however come into play for cooler stars where according to the Saha equation, the metals Ca, K and Na are only partially ionized. These elements are not sufficiently abundant for their bound-free absorption to affect the radiation field. Furthermore, in the wavelengths region for photoionization of these metals, especially K and Na, there may be significant chromospheric radiation available, including in particular the strong emission to be expected in the H and K lines of MgII at $\lambda 2800 \text{ \AA}$.⁽⁵⁾ Since there will be in any case very little ionization in the atmosphere, the blocking effect of ionized lines can be neglected.

Thus we suggest that while it still seems necessary to invoke unknown absorbants in the atmosphere of K6-M2 dwarfs, and while it is of course likely that such absorbants will continue to operate in cooler stars, one should take account of a possible over-ionization of K and Na in the very coolest stars, leading to an excess electron pressure and higher H^- opacity.

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- (2) Kandel, R. 1967. Ann. d'Astrophys. 30, 439
- (3) Vardya, M. S. 1966. M. N. 134, 347
- (4) Gingerich, O. 1964. Proc. 1st Harvard-Smithsonian Conf. on Stellar Atmospheres. SAO Special Report N° 167, p.108.
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CAPTIONS FOR FIGURES:

"THE ELECTRON PRESSURE IN THE ATMOSPHERES OF LATE-TYPE DWARFS"

- Fig. 1: Smoothed observed profiles of the CaI g line at $\lambda 4227$ A.
- Fig. 2: Comparison of observed and computed profiles. The curve numbered (1) is computed using the normal abundance: $A(\text{Ca})/A(\text{H})=6.5 \times 10^{-6}$. For the other curves this abundance has been multiplied by the number shown.
- Fig. 3: Same as Figure 2, but for a colder model: the disagreement becomes stronger.
- Fig. 4: The blend of the CaII K line and the Al I resonance line, between 3930 and 3945 A, in the spectrum of 61 Cyg B. Again, observed and computed profiles.
- Fig. 5: The Na D lines in the spectrum of 61 Cyg B and HD 88239, compared with computed profiles for $\theta_{\text{eff}}=1.16$ and $\theta_{\text{eff}}=1.25$. Note that H. L. Johnson (Bol. Obs. Ton. y Tac. 3, 305, 1964) assigns $\theta_{\text{eff}}=1.23$ to 61 Cyg B, and HD 88230 is most probably cooler, so that a strong disagreement exists for Na D.

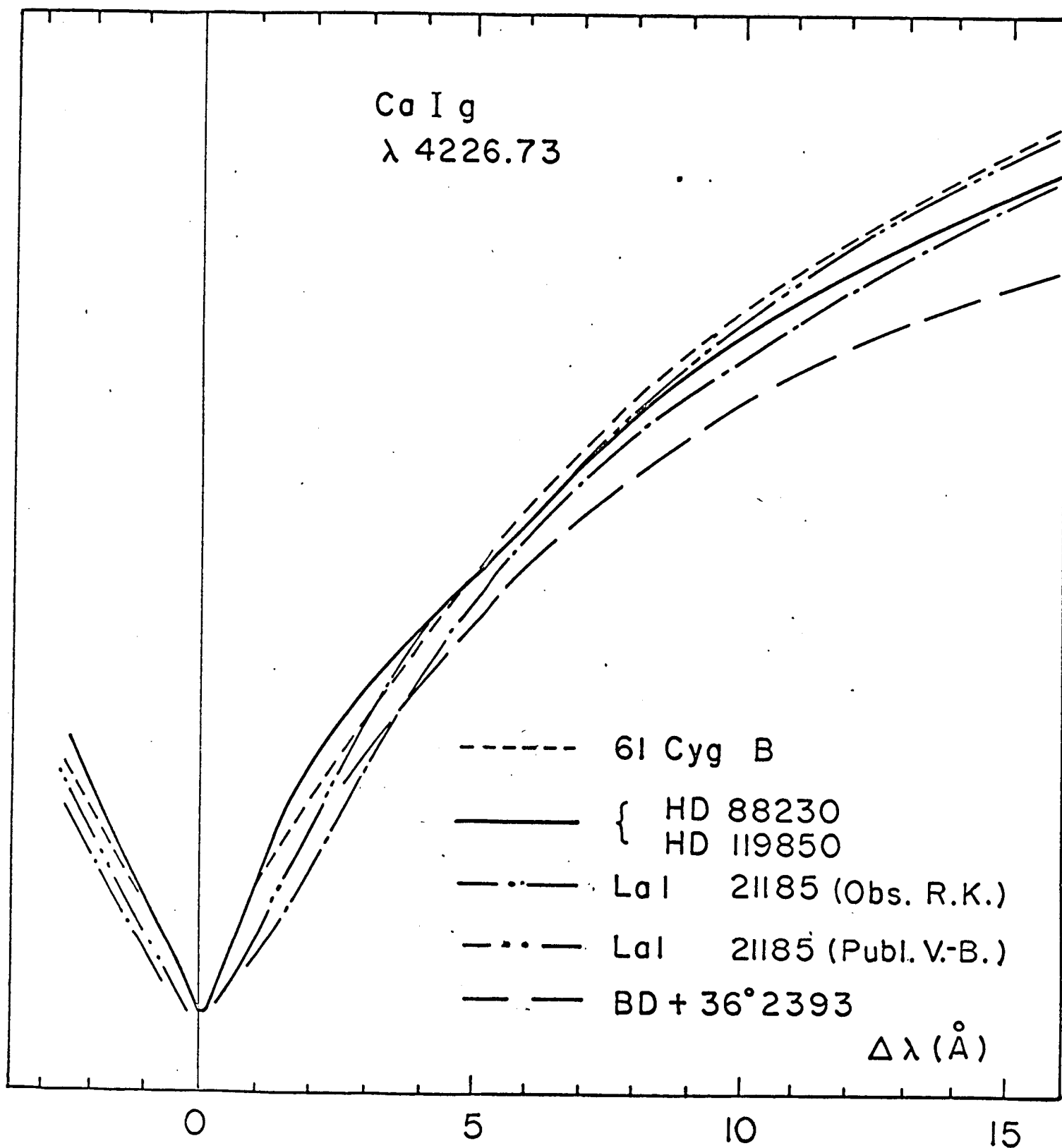


Figure 1

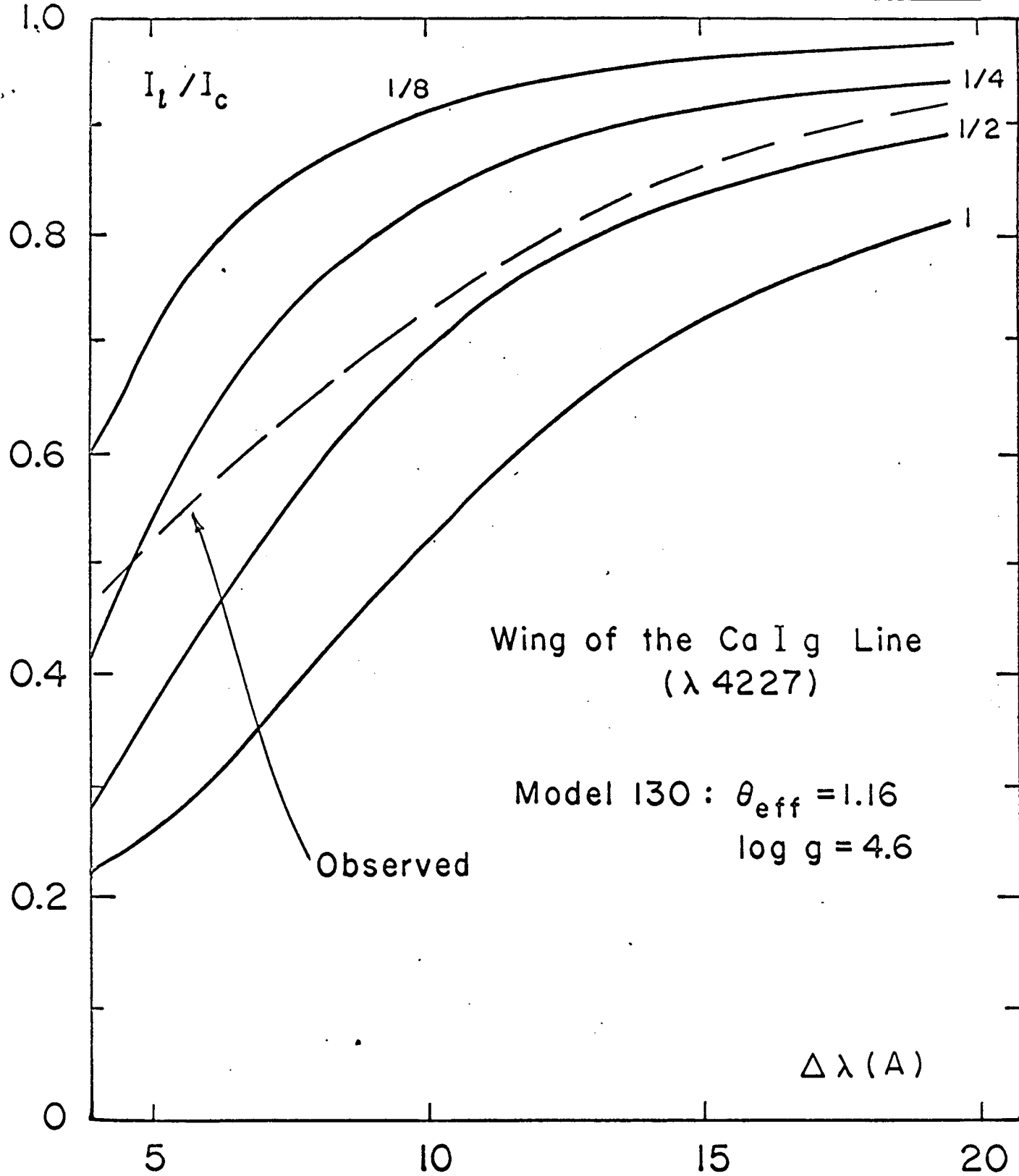
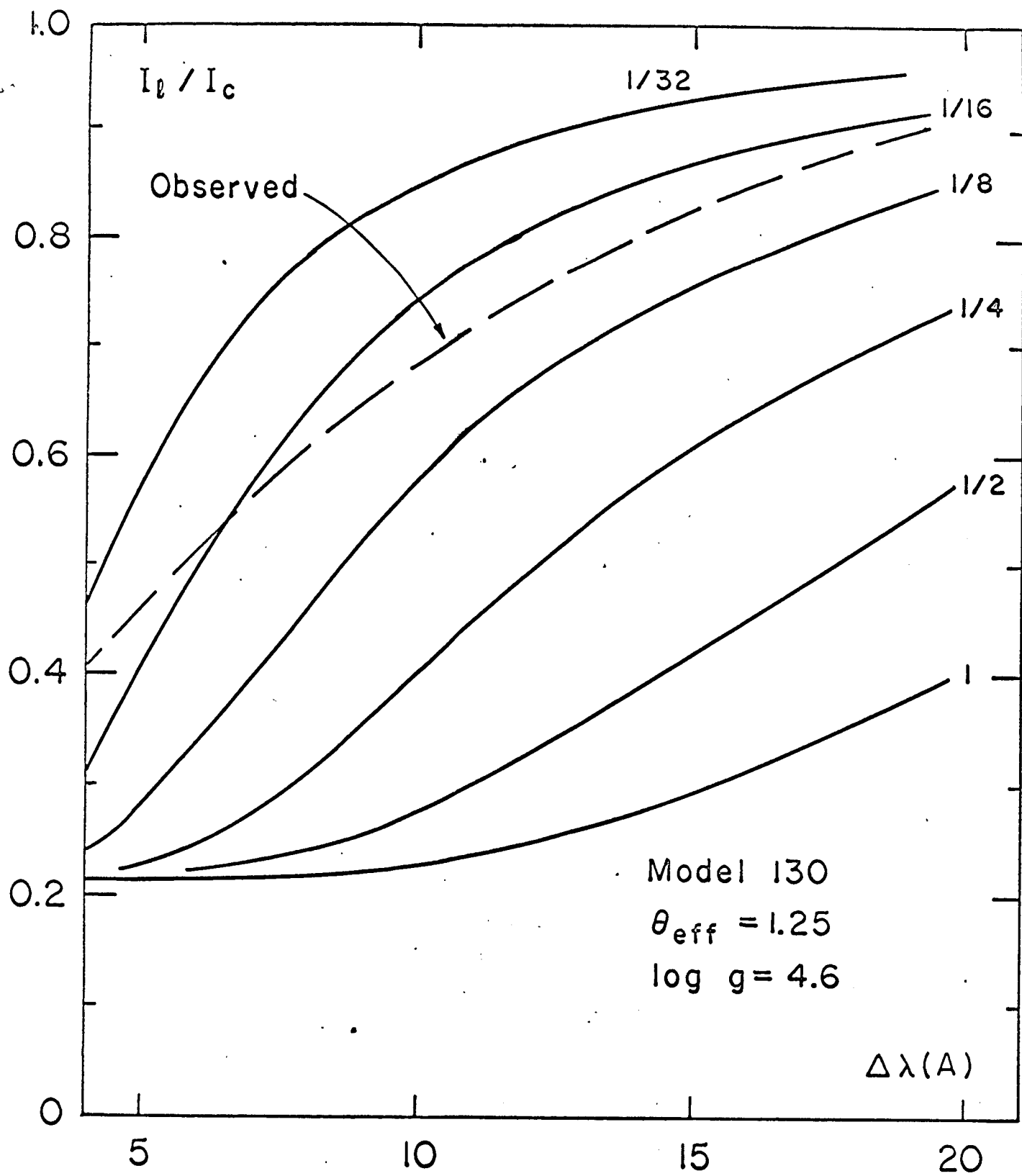
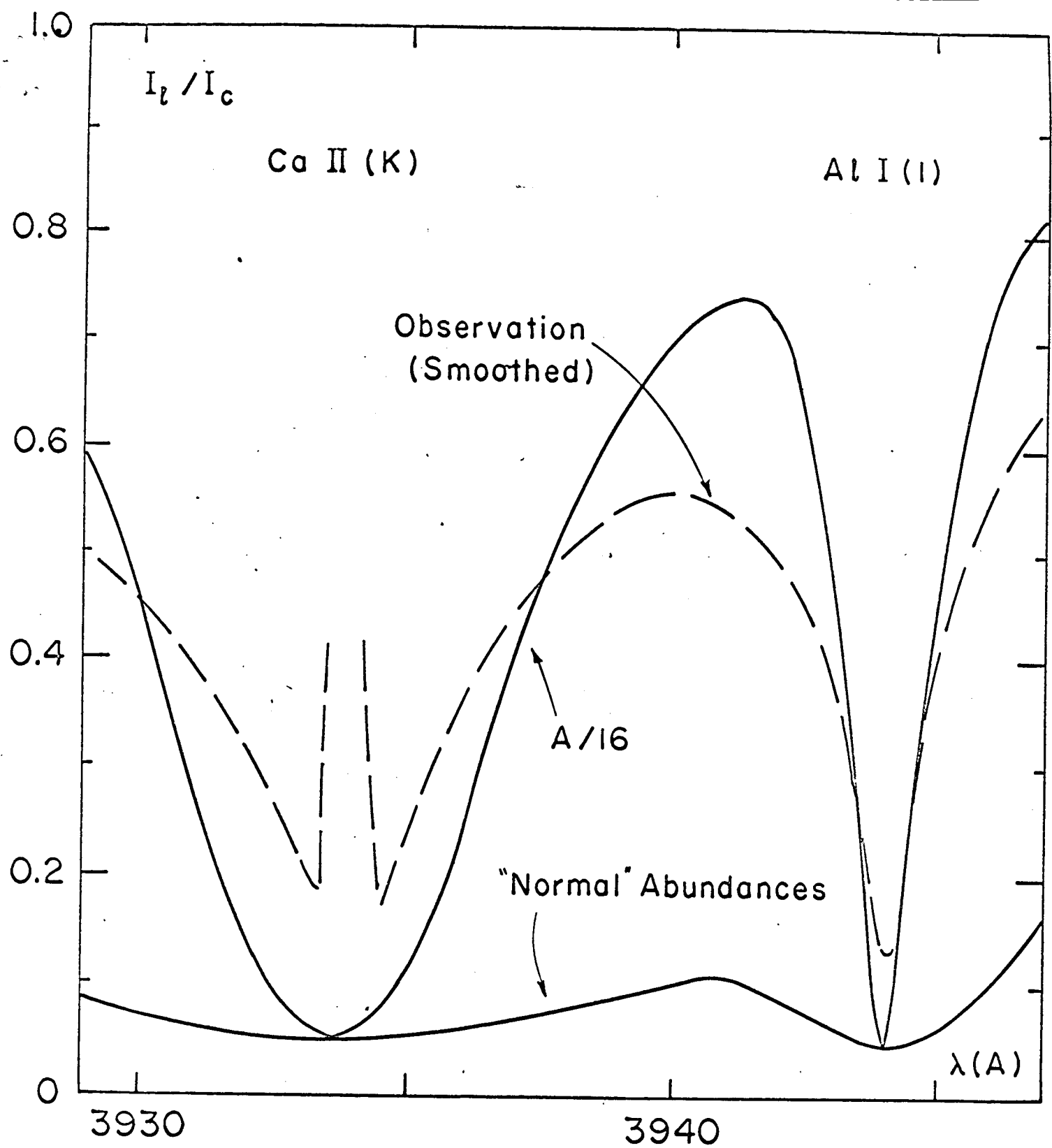


Figure 2



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Figure 3



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Figure 4

